Journal of Telecommunication, Electronic and Computer Engineering
ISSN: 2180 – 1843 e-ISSN: 2289-8131 Vol. 14 No. 4
jtec.utem.edu.my

Robotic Arm Gripper Using Force Sensor for Crop Picking Mechanism

A.R. Syafeeza, Norihan Abdul Hamid, Man Ling Eng, Guan Wei Lee, Hui Jia Thai, Azureen Naja Amsan
Machine Learning and Signal Processing (MLSP) Research Group,
*Centre for Telecommunication Research and Innovation (*CeTRI*),*
Faculty of Electronic Engineering and Computer Engineering (FKEKK),
Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia
syafeeza@utem.edu.my

Article Info

Article history:
Received June 16th, 2022
Revised Oct 12th, 2022
Accepted Nov 23rd, 2022

Index Terms:
Emerging Technology
Robot Fruit Picker
Gripper Force Sensor

Abstract

A dynamic gripper with qualities that resemble the human hand as closely as possible is sought after in the field of robotics. The idea of a robotic arm has been used in various cutting-edge technology fields, including agriculture, to assist people or farmers in carrying out regular tasks, such as gathering fruit, etc. The robot arm's end effector is one of the essential parts of the robot that we can configure based on their tasks, such as a spraying adaptor for fertilization function or a gripper for the picking mechanism. Since fruits have a delicate and fragile surfaces, it is vital to have a gripper with a smooth contact surface that can apply the right amount of force to pick the fruits without causing any bruising that can degrade the crop's quality. Hence, this paper proposes a robotic arm gripper design for the crop-picking mechanism using a force sensor as the main component of the Arduino Uno embedded system. The reliability result for the chili obtained is around 95% showing that this design is promising for designing an adaptive robotic arm gripper.

I. INTRODUCTION

A robotic arm is a mechanical arm that is usually programmable and performs functions similar to a human arm. The arm can be used independently or as part of a giant robot. The link of manipulators is connected by joints that allow for either rotational (as in an articulated robot) or translational (linear) movement. It can be thought of as a kinematic chain. The manipulator's kinematic chain ends with the effector, similar to a human hand. However, "robotic hand" is frequently used as a synonym for "robotic arm." In the market, there are seven different types of stationary robots. Stationary robots are robotic arms that perform tasks such as picking and placing, assembling, welding, finishing, and sorting. Articulated robotic arms, Cartesian or Rectangular Robots, Gantry Robots, Polar or Spherical Robots, Delta or Parallel Robots, and Cylindrical and Collaborative Robots/ Cobots are the different types of robots [1].

The robotic arm concept has been used in many areas of technological advancement, including agriculture. It is used in many tasks to assist humans/farmers in completing their daily activities in the field, such as picking fruits. The end of the effector of the robot arm is one of the essential parts of the robot that we can be configured based on their tasks, such as a spraying adaptor for fertilization function or a gripper for the picking mechanism. Since most fruits have delicate and fragile surface, it is vital to have a gripper with a smooth contact surface that can apply the right amount of force to pick the fruits without causing any bruise that can degrade the crops [2].

Various approaches have been introduced to design the robotic arm gripper. The work in [3] proposed an underactuated robotic gripper with two adaptive fingers using the Copley servo controller to control the input. Glick *et al.*, 2018 [4] investigated the combination of fluidic elastomer actuators and gecko-inspired adhesives to enhance existing soft gripper properties and generate new capabilities. Preidank, Detert, and Hirsch, 2017 [5] utilized optical proximity sensing with visible or infrared light to detect multiple inputs for touchless human-machine interfaces. A gripper with two Multi Joint Fingers (MJF) that achieves envelope grasping that adapts to the shape of the objects was introduced in [6]. The work in [7] stated that dynamic fingertip sensing is a cheaper and more accurate solution.

Generally, a robotic arm gripper aims to help the farmers conduct a self-gardening to ease them with harvesting fruits. Since most fruit harvests are fragile on the skin, a robotic arm gripper with a force sensor that can grip the fruit reasonably and does not damage the fruit is a decent idea [3]. Some challenges need to be addressed in modern agriculture so that the robot arm gripper can overcome the labor costs and human resources shortages in agriculture. Besides that, farm work requires professional techniques to provide the best quality crops or fruits. In this case, a robotic arm gripper is recommended as it can assist humans/ farmers in completing their daily activities in fields, such as picking fruits/crops. In addition, the current robots or automation utilized in agriculture is complicated and expensive [8].

This project seeks to adopt a low-cost force sensor and Arduino Uno embedded system to a robotic arm gripper for the different crop-picking mechanisms to help farmers who own small-scale operations and aid their operations. This project also involved the continuous 360 servo motor in controlling the movement of the gripper.

II. LITERATURE REVIEW

A. Arduino UNO

The Arduino UNO is an ATmega328-based microcontroller board, and UNO is an Italian word that means "one". It is a microcontroller in the Arduino Nano and Leonardo family [8]. The name Arduino UNO was chosen to commemorate the upcoming release of the Arduino UNO Board 1.0 microcontroller board. This board has digital I/O pins 14, a power jack, an analog I/ps-6, a ceramic resonator-A16 MHz, a USB connection, an RST button, and an ICSP header. These can support the microcontroller for further operation by connecting this board to the computer. An AC to DC adapter, a USB cable, or an external 9-volt battery with a voltage range of 7 to 20 volts can all be used to power this board [9].

B. Pressure Force Sensor

The Interlink FSR-402 and FSR-406 are the most common types of FSR. When pressure is applied to the sensing area, a variable resistor, or FSR, changes resistance. It is made up of several thin, bendable layers. More resistive carbon elements come into contact with the conductive traces as it is pressed, lowering resistance. FSRs are distinguished by a few key features, such as size, shape, and sensing range, and they are available in various sizes, shapes, and sensing ranges. The sensing area of most FSRs is either circular or rectangular. Small circular sensors, ideal for wide-area sensing, can provide more outstanding sensing field accuracy than the square FSRs. Another essential feature of the FSR is its rated sensing range, which specifies the minimum and maximum pressures that the sensor can distinguish. When the force rating is low, the FSR is more sensitive. Any pressure that exceeds the sensor's maximum range is unmeasurable (which can also damage the sensor). The sensor is an infinite resistor with no pressure (open circuit). The resistance between the two terminals will decrease as its presses harder on the head of the sensor, but it will return to its original values when the pressure is released. The easiest way to read the FSR is to create a voltage divider by connecting the FSR to a fixed-value resistor (usually 10k) [10][11]. Figure 1 shows the FSR 402 Pressure Force Sensor.

Figure 1. FSR 402 Pressure Force Sensor

C. Robotic Arm Gripper

A robotic arm gripper is a simple robot arm that aims to help grip objects. Grippers are devices that allow robots to pick up and hold objects in their most basic form. Manufacturers can automate key processes like inspection, assembly, pick-and-place, and machine tending using grippers with a collaborative robot (or 'cobot') arm. People can combine an arm's strength with a hand's dexterity using grippers, which are attached to the end of the arm like human hands. This combination opens up a new world of material handling possibilities for cobots, from stacking large boxes to handling small, delicate electronic components. Grippers for UR cobots come in various shapes and sizes [2].

Victor Scheinman, a mechanical engineering student at Stanford University, created his Stanford arm. This early robot became the first readily controllable gripper in 1969 after much toil in the school's machine and computer labs. Stanford's arm behaved better than the naughty (less controllable) Hydraulic Standard arm. It influenced the development of new robotics. Many of the gripper's design and control elements are still used today. A new variation, the two-finger angle gripper, appeared in the late 1970s. In this design, two fingers swing on a pivot point, closing on target objects such as a gate or a lobster claw [12].

A new gripper was developed in the late 1980s. Barett Technology Inc. of Cambridge, Massachusetts, licensed a three-finger grasper developed at MIT in 1990. The hand design of Barrett includes servo controllers, software, communication, and four brushless motors. Two fingers have an extra degree of freedom for various grasping options thanks to 180° synchronous lateral mobility. Late last year, Barrett Technology licensed the polymer-based SDM Hand, a grasper developed by Robert D. Howe and Aaron Dollar of Harvard University's School of Engineering and Applied Sciences. The flexible joints in the fingers of this robotic hand allow it to conform to and grip objects of various shapes and sizes without exerting excessive force or requiring precise positioning. Barrett anticipates the availability of production SDMs in 2011 [13]. Through many years of development of robotic arm grippers, robotic arm gripper can now be seen in many industries and other places that require the use of robotic arm grippers as it brings many benefits to human activities.

D. 360 Continuous Servo Motor

Servo motor technology has progressed in lockstep with advancements in industrial robots. The Servo motor was first invented and introduced in May 1834 by Moritz Jacobi. In 1834, the servo motor was not even known as a servo motor. It was known as the rotating electric motor. The early motors introduced were weak compared to the rotating motors used today. From the 1950s onwards, interest in factory automation grew in the United States, initially involving mechanisms like belt conveyors, automatic machinery, and industrial robots. In the 1950s and 1960s, as technology advanced, DC servo motors became more popular, and they began to replace troublesome hydraulic and pneumatic mechanisms in industrial robots. Meanwhile, in the 1980s, AC servo motors appeared equipped with practical benefits, such as making robots smaller and lighter. They now account for most servo motors used in modern industrial machinery [14].

A continuous rotation servo, also known as a full rotation or 360° servo, resembles a typical hobby servo in appearance.

A continuous rotation servo has a shaft that constantly spins with control over its speed and direction, in contrast to a standard servo motor that only rotates over a small range with precise control over the position. The servo's endpoints might vary, and many only rotate through roughly 170 degrees. Additionally, "continuous" servos that can complete a full 360-degree rotation are available. Figure 2 shows the 360 continuous servo motor.

Figure 2. 360 continuous servo motor

III. METHODOLOGY

A. Circuit Design

This section describes the circuit design of the Arduino-powered robotic arm gripper circuit to harvest the crops with the necessary force applied. The initial design stage started with component selections and circuit design based on the required characteristics. The designed circuit can be referred to in Figure 3. It is crucial to plan which components to use and how to assemble and organize them to prevent damaging the components. Each component may be connected with a resistor to prevent the strong power from continuously channeling into the components.

First, the first push button with red color is connected to pin number 2 on Arduino and ground. A resistor between 1k ohm and 2k ohm is connected to the push button to prevent the overflowing current that could damage the push button. The second push button with blue color is connected to pin number 4 on Arduino and ground. A resistor is also connected at this push button, between 1k ohm and 2k ohm. The blue-colored push button functions as a signal feeder for the Arduino so that the Arduino can proceed to the next step. Then continuous servo motor is installed within the robotic arm gripper to act like the human grip. By giving different commands to the continuous servo motor, the continuous servo motor will open or close, depending on the command. Suppose the command tells the servo motor to open the robotic arm gripper. In that case, the continuous servo motor will move in a particular direction to open the robotic arm gripper and vice versa. The servo motor has three wires that are connected to three different pins. The orange wire is connected to pin 9 to receive the signal from Arduino UNO. The red wire is connected to the +5V pin on Arduino Uno to get a power supply from it, and the brown wire of the continuous servo motor is then connected to the ground pin on Arduino Uno. The continuous servo motor will only move once the servo motor receives a signal from Arduino Uno's pin 9. A resistor is also connected between pin 9 and the orange wire of the continuous servo motor to prevent the overflow of power into the servo motor from the Arduino Uno power supply (+5V) pin.

Moreover, a force sensor is also used to detect any weight and to convert the raw data into electrical output signals back to the Arduino Uno to process it. The force sensor has two pins, and each of the pins does not have any polarity on it. This force sensor can be connected to the power supply on one side of the leg while the other side of the leg is connected to the pin and ground. The pin connections can be switched, and the force sensor can work as usual. One side of the leg of the force sensor will then be connected, with a resistor, to the A0 and A1 pins since two force sensors are required to detect the tension or weight. The force sensor here will be connected to the fingers of the robotic arm grippers to function as if it functions as human fingers.

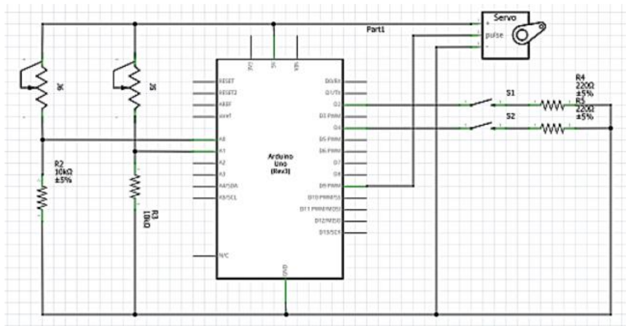

Figure 3. The circuit design of the circuit

B. Software Development

Arduino Software (IDE) software writes and loads the program into the Arduino microcontroller to execute the required task. Once the code is loaded onto the board, it can be used to collect the input, calculate, and display the output. The Arduino board is connected to a servo motor, force sensor, and push button to operate the circuit.

The circuit operation is as follows: Initially, the library for servo motors is called. Initialization is performed on the servo motor, the first and second buttons, and the analog readings from the first and second force sensors. Then, the two pins of the first and second force sensors are defined at pin locations A2 and A4, and these pins are unchangeable. The circuit will be reset each time the button is pressed, and the counter will count this process.

C. Designing the Schematic Circuit

The first step in this project is to create a circuit in Fritzing, as shown in Figure 4. The circuit is constructed, and then the component connections are examined. Three types of circuit connections of Arduino Uno exist in Fritzing software. The only three tasks in this project are drawing the schematic circuit, connecting the components to the Arduino Uno, and repeatedly testing each component's functionality. The flow of circuit design is as follows:

1. The circuit is designed and created using Fritzing software.
2. There are four options to be chosen from in Fritzing: breadboard, schematic, PCB and code design on top of the Fritzing. The design on the breadboard is determined to ease the connection in the schematic diagram.
3. The user has the flexibility to choose the required component's model in Fritzing. After selecting the suitable component, it can be placed around the breadboard in Fritzing.
4. Once the simulation and connection have been finalized in Fritzing, the coding of Arduino is the next step to be built in Arduino IDE. This step ensures that

the Arduino Uno can be coded and carry out the desired command.

5. Then, the coding is done and shown successfully in Arduino IDE. Next, the codes are inserted into the real Arduino Uno and tested.
6. If errors appear, it may take several trials to get the code, command, and output results right.

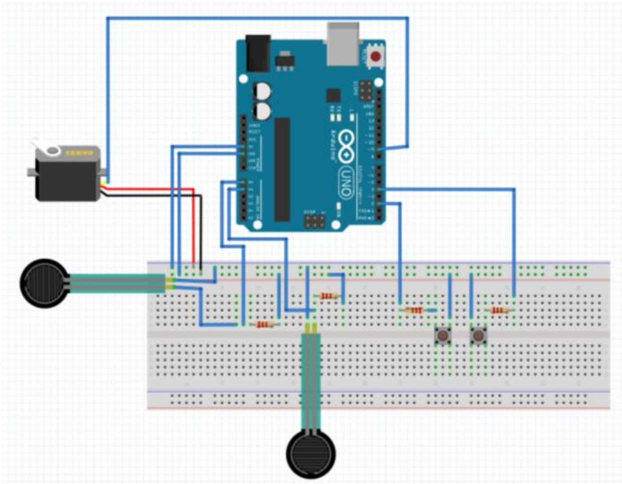

Figure 4. Breadboard view of the project

D. Prototype Testing

The prototype's power supply connector is connected to the laptop after the Arduino Uno's circuit construction and software testing have been accomplished. The intended wires are then connected to all male-female jumper wires. Next, the system is subjected to yet another evaluation to guarantee that the project's findings are pertinent and acceptable.

The circuit operates once the "ON" button is pressed and starts grabbing or gripping small objects, while the other button will act as the "OFF" button to turn off and reset everything back to its original state. The weight or tension of the small object, like chili, will be read by the force sensors placed on the fingertips of the robotic arm gripper. Figure 5 illustrates the prototype of a robotic arm gripper using the force sensor.

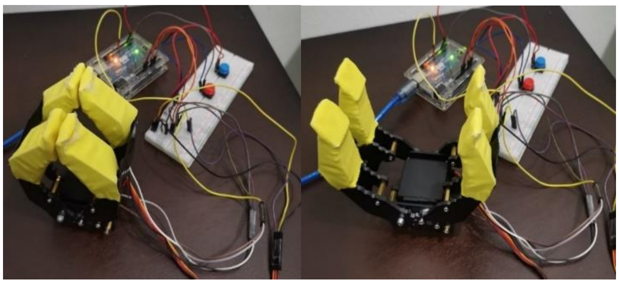

Figure 5. Prototype of robotic arm gripper using the force sensor

IV. RESULTS AND DISCUSSION

A. Results of Measurement

A base plate was placed in between two fingers of the gripper. The base plate supports the grasping of specific objects by acting as the finger of a human hand. Figure 6 shows four base plates attached to the gripper's eight claws, covering each pair of two claws. The purpose is to ease the gripping process. Then, each force sensor is mounted in the center of the finger accordingly. Four fingers are covered with a glove to increase the friction when grasping the object.

A test was conducted to gauge the gripper's capacity to grasp various-sized objects. The test object experiences a force when the gripper lifts it, and a determination can be made based on that force. After performing the grasp, the gripper will attempt to lift the object. When the test object is lifted, the serial monitor on Arduino IDE will show some value, meaning that grasp has occurred. Each object was brought towards the gripper 20 times to evaluate the gripper's dependability on the weight and size of various objects, and the number of successful grasps was recorded. With the aid of this test, it was possible to determine which objects the gripper could easily grasp and which gave challenges. Two categories, namely the successfully gripped and poorly grasped, were applied to evaluate the performance of the gripper. The test object must be brought towards the gripper for a successful grab, the gripper must conduct the pre-touch phase, and pressure can be read from the force sensor. Following that, the gripper should grasp the object and be able to hold on to it without human assistance while being hoisted. Otherwise, the gripper's hold was unsuccessful. Figure 6 displays some of the test objects.

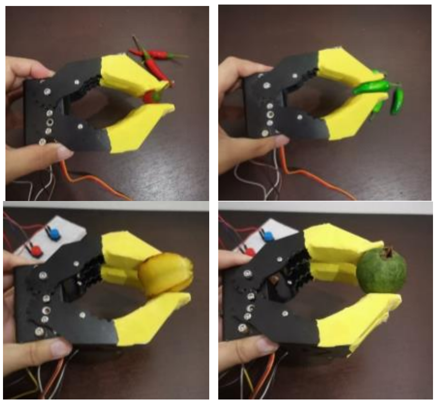

Figure 6. Successful grasp for red and green chili, starfruit, and guava

The force sensor reading during the gripping technique is displayed in Table 1 below. The chili was tested twice to check the reading from the force sensor and the reading was the highest at 70 N and 67 N, respectively. The starfruit was grasped at 58 N and 60 N reading. While the guava was grasped using 61 N and 55 N, respectively.

Table 1
Used objects and force sensor value

Object	Average Reading from Force Sensor, Newton (N)
Chili	68.5
Starfruit	59.0
Guava	58.0

Table 2
Results for test in successful grasp/attempt and percentage

Object	Successful grasps/ attempt	Reliability (%)
Chili	19/20	95
Starfruit	15/20	75
Guava	14/20	70

The data in Table 2 illustrates the simple objects for the gripper to grab and those that provide challenges. The chili was the most successful test object using a robotic arm gripper with a force sensor. The red and green chili could be grasped successfully in 19 out of 20 attempts. On the other hand, the starfruit has successfully grasped 15 times

out of 20 attempts, while the guava achieved 14 successful attempts out of 20.

B. Device Operation

After completing the project, the device's final functionality test was performed to ensure its functionality. The program was initially uploaded to Arduino using the Arduino IDE software. Next, the gripper will extend its fingers. The object is lifted by the gripper when the user raises the gripper. The gripper approaches the objects to pick them up. The blue push button must be pushed for the gripper to close its fingers and touch the object. At the same time, the force is being applied to the object. The force sensor, placed on the gripper's finger, converts the mechanical force into an electrical output signal that can be measured, converted, and standardized. The output signal is then displayed on the Arduino IDE serial monitor, which presents the amount of force applied to the object. The gripper can grip light objects such as chili, small starfruit, and small guava. Measurements were taken and recorded for each object when they were gripped.

C. Result Discussion

The gripper has been tested on various objects, and the results proved that the gripper could detect and grasp objects with different characteristics. The gripper is proven to be independent and adaptive depending on the required object to be grasped.

However, the gripper has several limitations. The object's surface can occasionally make it difficult for the force sensor to detect. This issue results in an inaccurate measurement of the pressure exerted on the object. This issue can be solved using the anti-slip technique to improve the object's ability to be held onto while being raised and shaken without damage.

The findings indicate that the gripper can easily handle small and large objects. However, the gripper struggles to hold intricate items or objects with specific shapes, like spheres. The guava and the starfruit were the two objects tested. The shape of the starfruit is irregular and has caused difficulty for the force sensor to detect pressure due to the uneven contact surface. In contrast, the spherical-shaped guava makes it challenging for the gripper to hold, and nearly no part of the fruit could be positioned to contact with the force sensors. Therefore, a sensor that can swiftly detect these objects is required to address the issues mentioned earlier and to keep the object from slipping off the finger. Another solution that could be taken is to utilize a wider region of slip detection. A touch sensor placed on the surface of the fingers could be another solution. Besides that, this issue might be resolved by placing an additional slip sensor on each finger.

V. CONCLUSION

In a nutshell, this project's main objective is to pick any crops without causing any bruise to the crop. This method has been created for others to utilize when it comes to self-home gardening and can be a good base reference when others want to use and modify the available project. The results show that this approach is feasible for light and small objects like chili.

This project can be enhanced and modified more for novice non-engineers to experiment with, as the code and devices to handle small crops, especially chilies, have already been created using simple components. In the future, this project could be extended to lift heavy objects toward becoming a universal adaptive robotic arm gripper.

ACKNOWLEDGMENT

The authors would like to acknowledge the support from the Machine Learning and Signal Processing (MLSP) research group under the Centre for Telecommunication Research & Innovation (CeTRI), Universiti Teknikal Malaysia Melaka (UTeM). This research is supported by the Ministry of Higher Education Malaysia (MOHE) through the fundamental research grant FRGS/1/2022/ICT02/UTEM/02/6.

REFERENCES

[1] A. K. Katti, "Multi Robot Localization assisted by Teammate Robots and Dynamic Objects," 2009.

[2] A. Kultongkham, S. Kumnon, T. Thintawornkul, and T. Chanthsopeephan, "The design of a force feedback soft gripper for tomato harvesting," *J. Agric. Eng.*, vol. 52, no. 1, 2021, doi: 10.4081/jae.2021.1090.

[3] B. Gao, S. Yang, H. Jin, Y. Hu, X. Yang, and J. Zhang, "Design and Analysis of Underactuated Robotic Gripper with Adaptive Fingers for Objects Grasping Tasks," pp. 987–992, 2016.

[4] P. Glick, S. A. Suresh, D. Ruffatto, M. Cutkosky, M. T. Tolley, and A. Parness, "A Soft Robotic Gripper with Gecko-Inspired Adhesive," *IEEE Robot. Autom. Lett.*, vol. 3, no. 2, pp. 903–910, 2018, doi: 10.1109/LRA.2018.2792688.

[5] S. Preidank, M. Detert, and S. Hirsch, "Multitouch touchless - A new approach with optical proximity sensing," *Proc. - 2017 7th Int. Work. Adv. Sensors Interfaces, IWASI 2017*, pp. 145–149, 2017, doi: 10.1109/IWASI.2017.7974235.

[6] S. Nomura, T. Tamamoto, K. Takeuchi, and K. Koganezawa, "Development of multi joint gripper and its dexterous grasping," *RO-MAN 2017 - 26th IEEE Int. Symp. Robot Hum. Interact. Commun.*, vol. 2017-January, pp. 1412–1417, 2017, doi: 10.1109/ROMAN.2017.8172489.

[7] C. Jackson, H. Vermaak, and G. Jordaan, "Force sensing for dynamic gripping, using a piezoelectric sensor," *IEEE Int. Symp. Ind. Electron.*, pp. 1371–1376, 2007, doi: 10.1109/ISIE.2007.4374800.

[8] K. Jha, A. Doshi, P. Patel, and M. Shah, "A comprehensive review on automation in agriculture using artificial intelligence," *Artif. Intell. Agric.*, vol. 2, pp. 1–12, 2019, doi: 10.1016/j.aiia.2019.05.004.

[9] "Arduino Uno WiFi," *https://docs.arduino.cc/retired/boards/arduino-uno-wifi*, 2022. .

[10] "Force-sensing resistor," *Wikipedia*. https://en.wikipedia.org/wiki/Force-sensing_resistor (accessed Sep. 15, 2022).

[11] "Interfacing Force Sensing Resistor (FSR) with Arduino," *Last Minute Engineers*. https://lastminuteengineers.com/fsr-arduino-tutorial/ (accessed Sep. 15, 2022).

[12] J. S. Shaw and V. Dubey, "Design of servo actuated robotic gripper using force control for range of objects," *2016 Int. Conf. Adv. Robot. Intell. Syst. ARIS 2016*, pp. 6–11, 2017, doi: 10.1109/ARIS.2016.7886619.

[13] Elisabeth Eitel, "A history of gripping and gripper technologies and the available options for today's engineer." https://www.machinedesign.com/markets/robotics/article/21833349/a-history-of-gripping-and-gripper-technologies-and-the-available-options-for-todays-engineer (accessed Sep. 15, 2022).

[14] Aspina, "What is a servo motor?" https://www.aspina-group.com/en/learning-zone/columns/what-is/004/ (accessed Sep. 15, 2022).